A COMPARISON OF THEORETICAL C IV EMISSION LINE STRENGTHS WITH ACTIVE REGION OBSERVATIONS OBTAINED WITH THE SOLAR EUV ROCKET TELESCOPE AND SPECTROGRAPH (SERTS)

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(Received 23 June, 1992; in revised form 26 August, 1992)

Abstract. Theoretical line ratios involving $2s\ ^2S - 3p\ ^2P$, $2p\ ^2P - 3s\ ^2S$, and $2p\ ^2S - 3d\ ^2D$ transitions in C IV between 312 and 420 Å are presented. A comparison of these with solar active region observational data obtained during a rocket flight by the Solar EUV Rocket Telescope and Spectrograph (SERTS) reveals good agreement between theory and experiment, with discrepancies that average only 22%. This provides experimental support for the accuracy of the atomic data adopted in the line ratio calculations, and also resolves discrepancies found previously when the theoretical results were compared with solar data from the S082A instrument on board *Skylab*. The potential usefulness of the C IV line ratios as electron temperature diagnostics for the solar transition region is briefly discussed.

1. Introduction

Emission lines arising from transitions in ions of the lithium isoelectronic sequence are frequently observed in the spectra of astrophysical objects, such as the solar transition region and corona (Sandlin *et al.*, 1986; Phillips *et al.*, 1982), as well as in laboratory plasmas (Davé *et al.*, 1987). They may be used to derive the electron temperature (T_e) of the emitting region through diagnostic line ratios, as discussed by, for example, Gabriel and Jordan (1972) and Kunc (1988). However, to calculate reliable theoretical ratios, accurate atomic data must be employed, especially for f-values and electron impact excitation rates (Dufton and Kingston, 1981).

Recently, Burke (1992) has calculated electron impact excitation rates for transitions in Li-like C IV with the **R**-matrix code of Burke and Robb (1975). Keenan *et al.* (1992) subsequently used these results to derive diagnostic line ratios for this ion, which were compared with intermediate spectral resolution solar observations from the S082A instrument on board *Skylab*. Unfortunately, the observed and theoretical line ratios often showed large discrepancies (of up to a factor of 3.1), which was suggested might be due to blending in the S082A data.

In this paper we compare the theoretical C IV line ratios with higher quality solar

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Solar Physics **144**: 69–74, 1993.

observations obtained with the Solar EUV Rocket Telescope and Spectrograph (SERTS), to investigate if the discrepancies noted above can be removed.

2. Theoretical Ratios

The model ion adopted for C IV has been discussed in detail by Keenan *et al.* (1992). Briefly, the eight energetically lowest LS states were included in the calculation, namely $2s\,^2S$, $2p\,^2P$, $3s\,^2S$, $3p\,^2P$, $3d\,^2D$, $4s\,^2S$, $4p\,^2P$, and $4d\,^2D$, making a total of 13 levels when the fine structure splitting in the doublets is included. Collisional excitation and de-excitation by electrons and spontaneous radiative de-excitation were the only atomic processes considered in the calculation, and the plasma was assumed to be optically thin. Further details may be found in Keenan *et al.* (1992).

In Figure 1 we plot the theoretical emission line ratios

$$R_1 = I(2s\,^2S - 3p\,^2P_{1/2,\,3/2})/I(2p\,^2P_{3/2} - 3s\,^2S)\,,$$

$$R_2 = I(2p\,^2P_{1/2} - 3d\,^2D_{3/2})/I(2p\,^2P_{3/2} - 3s\,^2S)\,,$$

and

$$R_3 = I(2p\,^2P_{3/2} - 3d\,^2D_{5/2})/I(2p\,^2P_{3/2} - 3s\,^2S)\,,$$

for a range of electron temperatures about that of maximum C IV fractional abundance in ionization equilibrium, $\log T_e = \log T_{\max} = 5.0$ (Arnaud and Rothenflug, 1985). The calculations in the figures were performed for an electron density of 10^{11} cm^{-3}, although we note that the line ratios are density insensitive for $N_e \leq 10^{13}$ cm^{-3}. We should point out that R_1 has already been plotted by Keenan *et al.* (1992), but has been included here for completeness.

3. Observational Data

The solar spectrum analysed in the present paper was that of active region NOAA 5464, including emission from the early stages of a subflare. The spectrum was recorded on Eastman Kodak 101–07 emulsion by the Solar EUV Rocket Telescope and Spectrograph (SERTS) during a rocket flight on 1989 May 5 at 17:50 UT. This instrument covered the wavelength region 235–450 Å, with a spectral resolution of better than 80 mÅ (FWHM) and a spatial resolution of 6 arc sec. It is discussed in detail by Neupert *et al.* (1992).

We have identified the following C IV emission lines in the SERTS active region spectrum: $2s\,^2S - 3p\,^2P_{1/2,\,3/2}$ (at 312.43 Å), $2p\,^2P_{1/2} - 3d\,^2D_{3/2}$ (at 384.03 Å), $2p\,^2P_{3/2} - 3d\,^2D_{5/2}$ (384.17 Å), and $2p\,^2P_{3/2} - 3s\,^2S$ (419.72 Å). The intensities of these lines (which have typical relative errors of $\pm 30\%$) were determined by fitting gaussian profiles to microdensitometer scans of the recorded spectrum.

The quality of the observational data are illustrated in Figures 2 and 3, where we plot the active region spectrum between 312–313 Å and 419–420 Å, respectively. In particu-

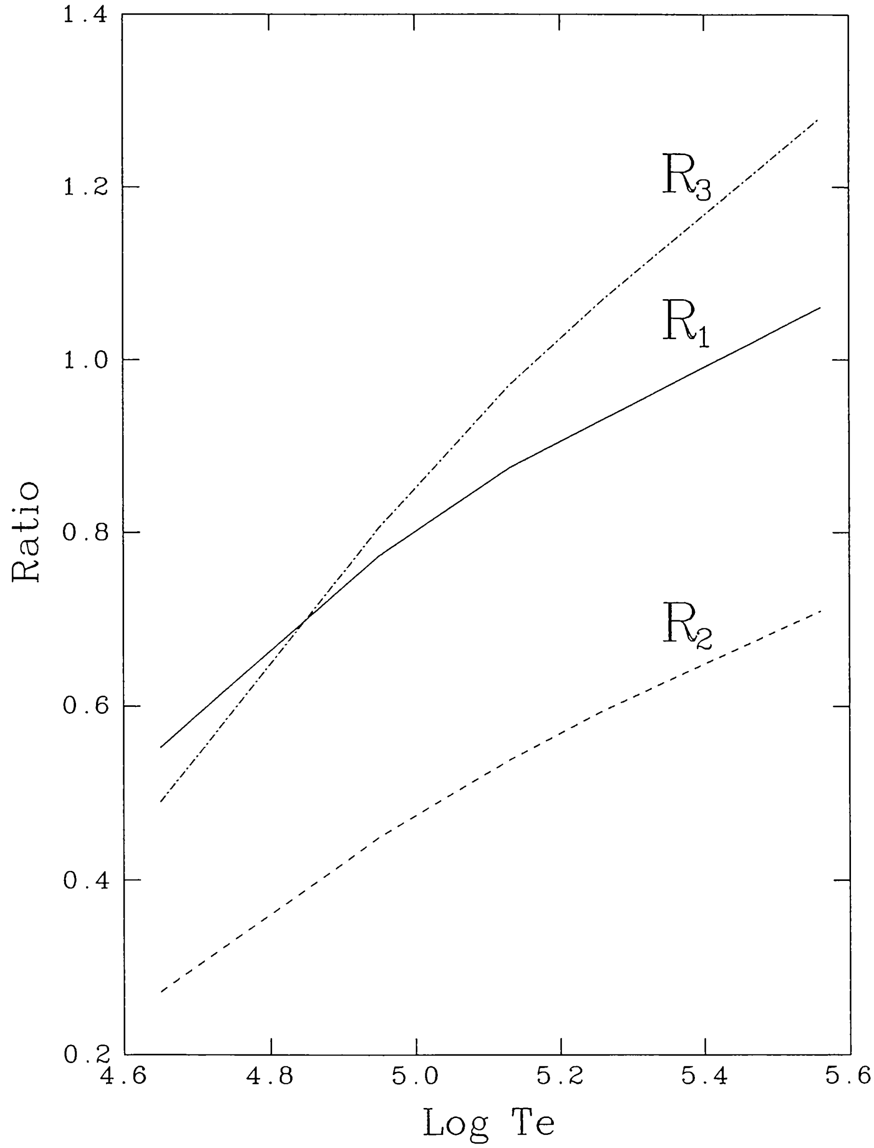

Fig. 1. The theoretical C IV emission line ratios $R_1 = I(2s\,^2S - 3p\,^2P_{1/2,\,3/2})/I(2p\,^2P_{3/2} - 3s\,^2S) = I(312.43\ \text{Å})/I(419.72\ \text{Å})$, $R_2 = I(2p\,^2P_{1/2} - 3d\,^2D_{3/2})/I(2p\,^2P_{3/2} - 3s\,^2S) = I(384.03\ \text{Å})/I(419.72\ \text{Å})$, and $R_3 = I(2p\,^2P_{3/2} - 3d\,^2D_{5/2})/I(2p\,^2P_{3/2} - 3s\,^2S) = I(384.17\ \text{Å})/I(419.72\ \text{Å})$, where I is in units of photon numbers, plotted as a function of electron temperature at an electron density of $N_e = 10^{11}\ \text{cm}^{-3}$.

lar, we can see from Figure 2 that the C IV 312.43 Å line is resolved from Fe XV 312.55 Å, which is not the case in solar spectra obtained with the S082A instrument on board *Skylab* (see Keenan *et al.*, 1992).

4. Results and Discussion

In Table I we list the observed C IV emission line ratios $R_1 = I(312.43\ \text{Å})/I(419.72\ \text{Å})$, $R_2 = I(384.03\ \text{Å})/I(419.72\ \text{Å})$, and $R_3 = I(384.17\ \text{Å})/I(419.72\ \text{Å})$, along with the theoretical results from Figure 1 at the temperature of maximum C IV fractional abundance in ionization equilibrium, $\log T_{\max} = 5.0$ (Arnaud and Rothenflug, 1985). An

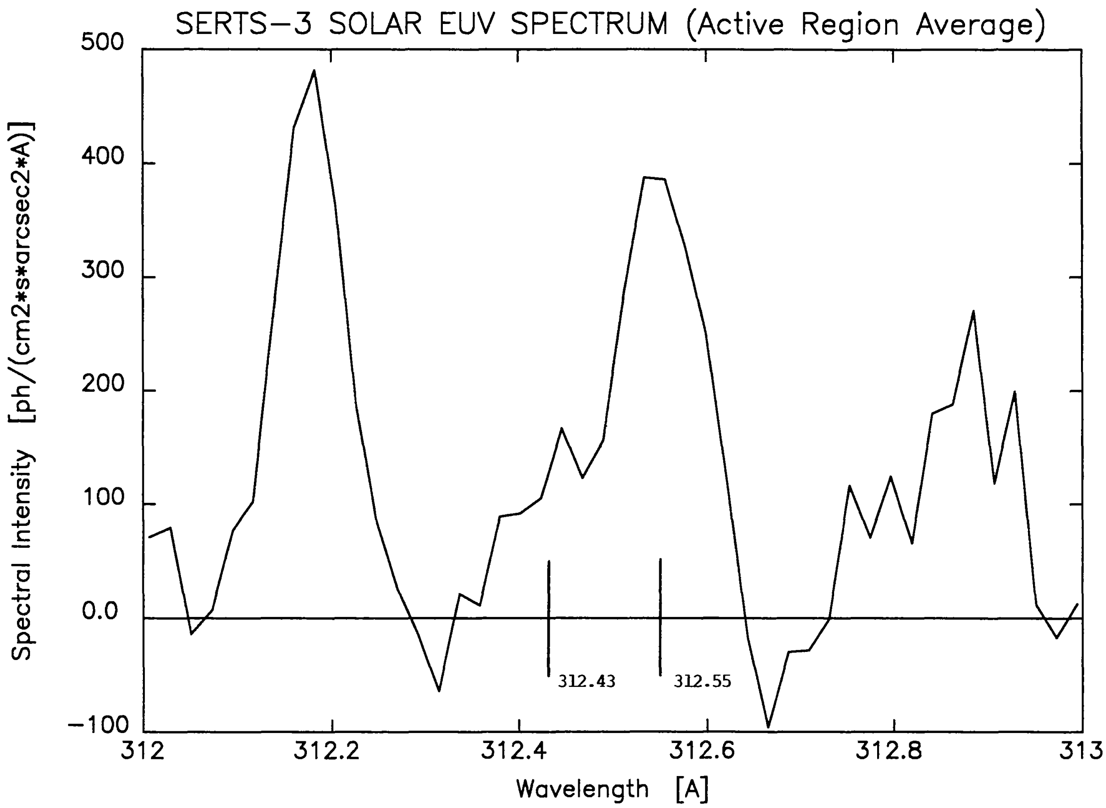

Fig. 2. Plot of the active region spectrum obtained with SERTS in the wavelength interval 312–313 Å. The C IV 312.43 Å and Fe XV 312.55 Å features are marked on the spectrum by lines.

TABLE I

Observed and theoretical C IV emission line ratios

λ (Å)	$R_{obs} = I(\lambda)/I(419.72$ Å$)$[a]	R_{theory}[b]
312.43	0.97 (R_1)	0.80
384.03	0.67 (R_2)	0.48
384.17	0.69 (R_3)	0.85

[a] $I(419.72$ Å$) = 7.2$ photons cm^{-2} s^{-1} arc sec^{-2}.
[b] Calculated at the electron temperature of maximum C IV fractional abundance in ionization equilibrium, $\log T_e = \log T_{max} = 5.0$ (Arnaud and Rothenflug, 1985).

inspection of the table reveals that agreement between theory and observation is good, with discrepancies that do not exceed 28% and average only 22%. This provides experimental support for the accuracy of the atomic data that have been adopted in the line ratio calculations, as the $2s\,^2S - 3p\,^2P_{1/2,\,3/2}$, $2p\,^2P_{1/2,\,3/2} - 3d\,^2D_{3/2,\,5/2}$, and $2p\,^2P_{3/2} - 3s\,^2S$ lines are in the coronal approximation (Elwert, 1952), and hence the values of $R_1 - R_3$ depend principally on the ratio of the relevant electron impact excitation rates. However, more importantly, it also resolves the serious discrepancy between theory and observation found by Keenan *et al.* (1992) for line ratios involving

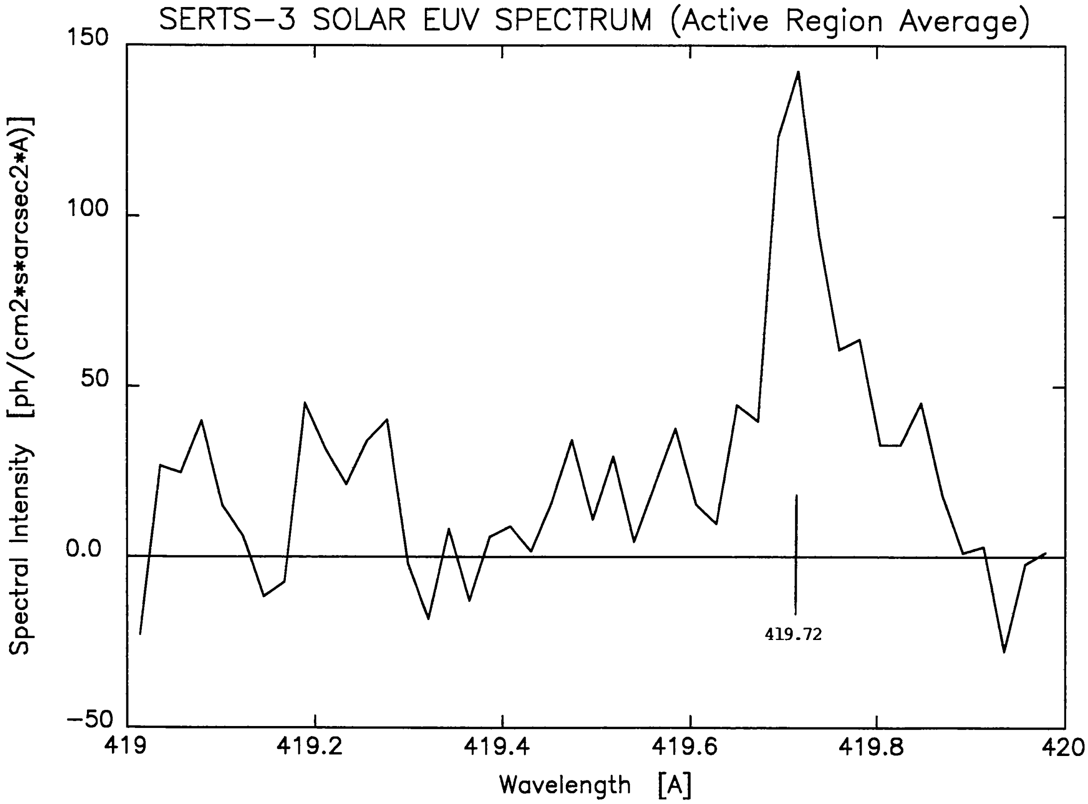

Fig. 3. Plot of the active region spectrum obtained with SERTS in the wavelength interval 419–420 Å. The C IV 419.72 Å feature is marked on the spectrum by a line.

the $2s\ ^2S - 3p\ ^2P_{1/2,\ 3/2}$ lines at 312.43 Å, which was probably due to blending of this feature with Fe XV 312.55 Å in the lower spectral resolution S082A observations. In addition, the present results imply that the 419.72 Å line flux is due primarily to C IV rather than Ca X (Behring *et al.*, 1976; Dere, 1982), at least for non-flaring solar features.

Finaly, we note that the ratios in Figure 1 are quite sensitive to variations in the electron temperature, and hence in principle may be useful as T_e-diagnostics for the solar transition region. For example, R_1 varies by 94% between $\log T_e = 4.6$ and 5.4, while R_2 changes by a factor of 2.8 over the same temperature interval. However these ratios would need to be determined to a much higher degree of accuracy than is possible with the SERTS instrument for reliable temperatures to be derived. (The typical $\pm 40\%$ error in the C IV line ratios deduced from SERTS data would lead to *at least* a factor of 3 uncertainty in the derived T_e.) In the future, accurate measurements for C IV should be possible using the Coronal Diagnostic Spectrometer on board SOHO (Harrison, 1990).

Acknowledgements

We would like to thank Profs. A. E. Kingston and P. G. Burke for their continued interest in this work. ESC and VMB are grateful to the SERC for financial support. This work was supported by NATO travel grant 0469/87 and the Nuffield Foundation. The SERTS rocket program was funded under NASA RTOP 879-11-38.

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